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ON THE WIRELESS LOCAL AREA NETWORK DESIGN PROBLEM WITH PERFORMANCE GUARANTEES

by

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Abstract

In this paper, we propose a model for the wireless local area network (WLAN) design problem with performance guarantees. This problem consists of selecting the location of the access points (APs) and selecting the power and the channel of each AP. The performance guarantees we refer to are coverage and minimum bandwidth guarantees. Since this problem is $\mathcal{NP}$-hard, we propose a tabu search algorithm to find solutions for real-size instances of the problem. Finally, numerical results are presented. The results show that good solutions can be found with the proposed algorithm in a reasonable amount of time.

Keywords: wireless local area network (WLAN); network design and planning; mathematical model; tabu search.

Résumé

Dans cet article, nous proposons un modèle pour la conception des réseaux sans fil WLAN (*Wireless Local Area Network*) avec garanties de performance. Ce problème consiste à sélectionner la localisation et la configuration des APs (Access Points) tout en considérant une couverture minimale ainsi qu'un débit minimum pour chaque station mobile. Un modèle de programmation mathématique à variables entières est proposé pour ce problème ainsi qu'une heuristique basée sur le principe de la recherche avec tabous pour trouver de bonnes solutions.

Mots-clés: réseaux sans fil WLAN; conception et planification des réseaux; modèle mathématique; recherche avec tabous.

1 Introduction

Over the last years, the number of wireless local area networks (WLANs) have grown at an explosive rate. The most important advantages of using WLANs are mobility and flexibility. Indeed, the WLAN users are allowed to roam freely and this type of network can be deployed extremely rapidly because it reduces the need for construction due to the cabling. However, still today, the performance and security of the WLAN technologies are worse than for the wired LAN techologies.

There are two types of wireless networks: independent (or ad-hoc) and infrastructure networks. In an independent network, mobile stations communicate directly with each other whereas, in an infrastructure network, the stations communicate using access points (APs). An AP is basically a device performing the wireless-to-wired bridging functions. The stations associated to an AP are forming a basic service set (BSS) and chained BSSs together with a LAN is call an extended service set (ESS). Each AP uses a specified signal power level and a channel to communicate with the stations. For more technical information concerning the WLANs, see the book by Gast [8].

Actually, the planning of a WLAN is typically done by trial-and-error or by using a computer-based planning tool to evaluate several AP placement and configuration scenarios and to find the channel assignment (e.g, see Hills [11]). However, since the number of APs increased continuously in large-scale WLANs, these optimization approaches can be long and complex.

In this paper, we tackle the global design problem of infrastructure WLANs with performance guarantees. This problem consists of jointly selecting the location of the APs and selecting the power and the channel of each AP. The performance guarantees we refer to are coverage and minimum bandwidth guarantees. The objective is to minimize the number of APs to install in the network.

The literature contains many articles relating to WLAN design problems, but the global WLAN design problem has not been considered before. In fact, these articles focus on a portion of the global problem, including the AP placement problem (Adickes *et al.* [1], Abolhassani, Salt and Dodds [2], Ali [3], Aguado-Agelet *et al.* [4], Ji, Sarkar and Li [13], Kamenetsky and Unbehaun [14], Tang, Man and Kwong [18], Tongcheng and Chundi [19], and Wu, Lee and Chen [20]), the joint AP placement and channel selection problem (Rodrigues, Mateus and Loureiro [17]) and the joint AP placement

and power selection problem (Park, Yook and Park [16]).

This paper is organized as follows. Section 2 presents the mathematical model for the global WLAN design problem and in Section 3, a tabu-based heuristic algorithm is proposed. Section 4 presents numerical results for a set of randomly generated problems. The first subsection of Section 4 presents the propagation model used for the tests, the second subsection presents a lower bound used to assess the performance of the proposed approach and the last subsection of Section 4 presents the numerical results and contains an analysis of these results. Conclusions and further works are presented in Section 5.

2 The WLAN Design Problem

In this section, we present the global WLAN design problem.

2.1 Problem Formulation

For the global WLAN design problem, the following information is considered known:

- the location of the demand points and the potential sites to install the APs;
- the maximum number of stations for each demand point;
- the set of power levels available;
- the set of non-overlapping channels available;
- the minimum bandwidth required for each station;
- the minimum signal to noise ratio (SNR) to reutilize a channel;
- the attenuation ratios between the demand points and the potential sites;
- the distances between the potential sites;
- the minimum bandwidth value per station according to the number of stations in a BSS.

We make the following assumptions concerning the organization of the WLAN:

- the network may be installed on multiple floors;

- the network operates in the infrastructure mode;
- the data rate (under ideal conditions) between each station and the associated AP is fixed (i.e., in order to guarantee the minimum bandwidth for each station, we do not allow that the data rate be automatically selected by the APs).

Solving the problem involves selecting the location of the APs, selecting the power and the channel of each AP. The objective of the problem is to minimize the number of APs subject to all of the information and by taking into account the assumptions described above.

2.2 Notation

The following notation is used throughout this paper. The notation is composed of sets, decision variables, constants and functions.

Sets: Let I be the set of demand points (where n_i is the maximum number of stations in the demand point $i \in I$), J, the set of potential sites to install the APs, P, the set of power levels available (in watt) and C, the set of non-overlapping channels available.

Decision Variables: Let w_j be a 0–1 variable such that $w_j = 1$ if and only if an AP is installed at site $j \in J$, x_{ij}, a 0–1 variable such that $x_{ij} = 1$ if and only if demand point $i \in I$ is associated to the AP installed at site $j \in J$, y_j^p, a 0–1 variable such that $y_j^p = 1$ if and only if the power $p \in P$ is used in the AP installed at site $j \in J$ and, finally, let z_j^c be a 0–1 variable such that $z_j^c = 1$ if and only if the channel $c \in C$ is used in the AP installed at site $j \in J$.

Constants: Let p_{min} be the minimum signal power (in watt) form an AP necessary to be associated to this AP, t_{min}, the minimum bandwidth (in bps) required by each station and d_{min}, the minimum SNR to reutilize a channel.

Functions: Let $\alpha(i,j)$ be the attenuation ratio from service point $i \in I$ to site $j \in J$ ($0 \leq \alpha(i,j) \leq 1$), $\beta(j,j')$, the attenuation ratio between the sites $j \in J$ and $j' \in J$ and finally, let $\delta(n)$ be the minimum bandwidth (in bps) in a BSS containing n stations ($n > 0$) ($\delta(0)$ is set to $\delta(1)$).

2.3 The Mathematical Model

The model for the global WLAN network design problem with performance guarantees, denoted WNDP, can now be given.

WNDP:

$$\min_{\mathbf{w},\mathbf{x},\mathbf{y},\mathbf{z}} \sum_{j \in J} w_j \tag{1}$$

subject to

Demand point assignment constraints

$$\sum_{j \in J} x_{ij} = 1 \quad (i \in I) \tag{2}$$

$$x_{ij} \leq w_j \quad (i \in I, j \in J) \tag{3}$$

$$\left(p_{min} - \alpha(i,j) \sum_{p \in P} py_j^p \right) x_{ij} \leq 0 \quad (i \in I, j \in J) \tag{4}$$

$$\left(\alpha(i,j') \sum_{p \in P} py_{j'}^p - \alpha(i,j) \sum_{p \in P} py_j^p \right) x_{ij} \leq 0 \quad (i \in I, j < j', j, j' \in J) \tag{5}$$

AP power level uniqueness constraints

$$\sum_{p \in P} y_j^p = w_j \quad (j \in N) \tag{6}$$

AP channel value uniqueness constraints

$$\sum_{c \in C} z_j^c = w_j \quad (j \in N) \tag{7}$$

Minimum bandwidth constraints

$$t_{min} - \delta \left(\sum_{i \in I} n_i x_{ij} \right) \leq 0 \quad (j \in J) \tag{8}$$

Channel reutilization constraints

$$\left(d_{min} \sum_{\substack{j' \in J \\ j' \neq j}} \left(\beta(j,j') z_{j'}^c \sum_{p \in P} py_{j'}^p \right) - p_{min} \right) z_j^c \leq 0 \quad (j \in J, c \in C) \tag{9}$$

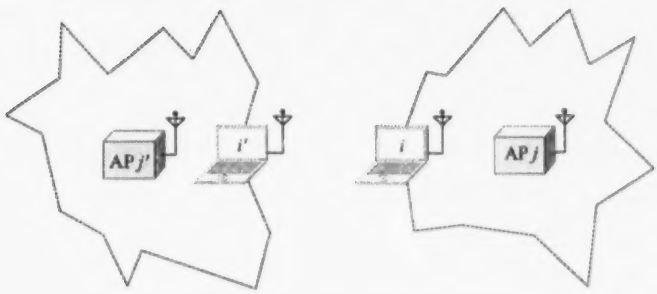

Figure 1: Illustration of two APs and demand points

Integrality constraints

$$\mathbf{w} \in \mathbf{B}^{|J|}, \mathbf{x} \in \mathbf{B}^{|I||J|}, \mathbf{y} \in \mathbf{B}^{|J||P|}, \mathbf{z} \in \mathbf{B}^{|J||C|}. \tag{10}$$

The objective function (1) of WNDP represents the number of APs installed in the network. Constraints (2) require that each demand point be associated to exactly one AP and constraints (3) impose demand point $i \in I$ be associated to site $j \in J$ only if an AP is installed at this site. Constraints (4) require that demand point $i \in I$ may be associated to the AP installed at site $j \in J$ only if the power of the signal form this AP is greater or equal to p_{min} and constraints (5) impose that each demand point be associated to the nearest AP (in term of the power). Constraints (6) and (7) impose respectively that exactly one power and exactly one channel be selected for each AP. Constraints (8) require the bandwidth of each station be greater or equal to t_{min} and constraints (9) are channel reutilization constraints. Constraints (10) are integrality constraints.

Proposition 1. Constraints (9) are valid for WNDP.

Proof. The following equation is a lower bound on the maximum power of noise using channel $c \in C$ at demand point $i \in I$ associated to AP $j \in J$ from the BSS served by the AP $j' \in J \setminus \{j\}$ (see Figure 1).

$$\underline{N}_{max}(j, j', c) = \beta(j, j') z^c_{j'} z^c_j \sum_{p \in P} p y^p_{j'}. \tag{11}$$

As a result,

$$\underline{N}_{max}(j,c) = \sum_{\substack{j' \in J \\ j' \neq j}} \left(\beta(j,j') z^c_{j'} \sum_{p \in P} p y^p_{j'} \right) z^c_j \tag{12}$$

is a lower bound on the maximum power of noise using channel $c \in C$ at demand point $i \in I$ associated to AP $j \in J$. The proposition follows since the minimum power of the signal within a BSS is p_{min} and the SNR should be greater of equal to d_{min}. □

Proposition 2. The following inequality, representing the minimum number of APs to install in the network is valid for WNDP.

$$\sum_{j \in J} w_j \geq \left\lceil \frac{\sum_{i \in I} n_i}{n_{max}} \right\rceil \tag{13}$$

where n_{max} is the maximum number of stations n associated to an AP such that the inequation $\delta(n) \geq t_{min}$ is respected. This inequality will be used to improve the linear relaxation of a relaxed version of the model used as a lower bound.

WNDP is a nonlinear integer mathematical programming model since constraints (4), (5), (8) and (9) are nonlinear.

Proposition 3. Constraints (4) and (8) can be linearized by adding variables and constraints.

Proof. Let x^p_{ij} be a 0–1 variable such that $x^p_{ij} = 1$ if and only if demand point $i \in I$ is associated to the AP installed at site $j \in J$ and using power $p \in P$. As a result, constraints (4) can be replaced by

$$x_{ij} = \sum_{p \in P} x^p_{ij} \quad (i \in I, j \in J) \tag{14}$$

$$x^p_{ij} \leq y^p_j \quad (i \in I, j \in J, p \in P) \tag{15}$$

$$p_{min} x_{ij} - \alpha(i,j) \sum_{p \in P} p x^p_{ij} \leq 0 \quad (i \in I, j \in J) \tag{16}$$

constraints (8) by

$$\sum_{i \in I} x_{ij} \leq n_{max} \quad (j \in J) \tag{17}$$

where n_{max} is the maximum number of stations n associated to an AP such that the inequation $\delta(n) \geq t_{min}$ is respected. □

Proposition 4. WNDP is $\mathcal{NP}$-hard.

Proof. Set $P := \{p_{min}\}$, $|C| := 1$, $d_{min} := 0$, $t_{min} := 0$ and $n_i = 1$ for all $i \in I$. In that context, an

algorithm for WNDP can solve the minimum set covering problem (see Nemhauser and Wolsey [15]) since the set I can represent the set of elements and J the set of subsets such that $\alpha(i,j) = 1$ if the element $i \in I$ is in the subset $j \in J$ and $\alpha(i,j) = 0$ otherwise. The proposition follows since the minimum set covering problem is $\mathcal{NP}$-hard (see Garey and Johnson [7]). □

Since WNDP is $\mathcal{NP}$-hard, we concentrate our efforts on the development of heuristics.

3 The Tabu Search Algorithm

In this section, we propose a tabu search (TS) algorithm for WNDP, called TS-WNDP. The basic principle of the tabu search is to define a set of possible solutions, and starting from the current solution, to find a better one in its neighborhood. A neighborhood is a set of solutions that are found by applying an appropriate transformation of the current solution. In order for the algorithm to move away from a local minimum, the search allows moves resulting in a degradation of the objective function value, thus avoiding the trap of local optimality. To prevent the search from cycling, solutions obtained recently and moves that reverse the effect of recent moves are considered tabu. For more details about tabu search, see the book by Glover and Laguna [9].

The following notation is used in the presentation of TS-WNDP. Let σ_j be the state of the site $j \in J$ such that $\sigma_j = 0$ if there is no AP installed at site j and $\sigma_j = p$ (for $p \in P$) if an AP using power p is installed at site j.

Let $\mathbf{y}(\sigma)$ be the vector $\mathbf{y}$ when the state vector of all sites σ is fixed.

In the next subsection, we propose an approach to solve WNDP(σ), i.e., the model WNDP when the state vector is fixed and the objective function is rewritten as

$$\min_{\mathbf{w},\mathbf{x},\mathbf{y},\mathbf{z}} \sum_{j \in J} w_j + \sum_{j \in j} \theta \left(\sum_{i \in I} n_i x_{ij} - n_{max} \right)^+ \tag{18}$$

where $(x)^+ = \max\{0, x\}$ and θ is a penalty factor.

3.1 Solving WNDP(σ)

In fact, when vector $\mathbf{y}$ is fixed, WNDP can be reduced to the graph coloring problem. Indeed, when vector $\mathbf{y}$ is fixed, vector $\mathbf{w}$ is determined using constraints (3) and the objective function, vector $\mathbf{x}$

using constraints (2), (5) and (5) and vector $\mathbf{z}$ by finding the channel assignment problem respecting constraints (9). This problem is $\mathcal{NP}$-hard [7] and can be solved by an algorithm for the graph coloring problem. In this paper, we use the DSATUR heuristic [5] for this problem.

3.2 Solution Space and Neighborhood Structure

Let $\mathbf{w}(\sigma)$, $\mathbf{x}(\sigma)$ and $\mathbf{z}(\sigma)$ be a solution of WNDP(σ). The solution space is thus $S = \{\mathbf{w}(\sigma), \mathbf{x}(\sigma), \mathbf{y}(\sigma), \mathbf{z}(\sigma)\}_{\sigma \in E}$ where E is the set of all possible states for the sites of the network, including those states that correspond to infeasible solutions. Note that $|E| = (|P| + 1)^{|J|}$.

Let $s \in S$ be a solution. $N(s)$ is called the neighborhood of s and consists of the solutions obtained by performing all possible moves. Each move consists in changing the state of a given site in the current solution. As a result, the number of moves required to explore all the neighborhood of any given solution is $|J||P|$.

3.3 Tabu Moves and Aspiration Criterion

Each move of tabu search consists of modifying the state of a given site in the current solution. At each iteration of the search, we determine the best move (among the $|J||P|$ moves) while taking into account the tabus as well as the aspiration criterion. The chosen site is declared tabu for a number of iterations that is randomly determined according to a uniform discrete distribution on the interval $[L, U]$.

The aspiration criterion states that if the use of tabu site allows us to discover a solution better than any other found so far, we may remove the tabu from this site.

3.4 The Tabu Algorithm

We now proceed to a detailed description of TS-WNDP.

Algorithm TS-WNDP

Step 1: (Initial solution)

Find an initial solution using the initial heuristic presented in the next subsection.

Repeat Steps 2 to 3 for MaxIter iterations

Step 2: (Exploring the neighborhood)

2.1 Determine the best move while taking into account the tabus and the aspiration criterion. For each move $\sigma \rightarrow \sigma'$, which modifies the state of a given site in the current solution, we solve WNDP(σ') as described in the Section 3.1. The cost of a solution is given by the objective function (18).

2.2 Determine the number of iterations according to a uniform distribution on the interval $[L, U]$ for which the chosen site is tabu.

Step 3: (Best solution update)

If the cost of the current solution is less than the cost of the best solution found so far, update this best solution.

3.5 The Initial Heuristic

We now describe an initial heuristic (IH), called IH-WNDP, able to find an initial solution for TS-WNDP.

IH-WNDP generates at most $|P|$ solutions corresponding to the installation of APs using power p for $1 \leq p \leq |P|$. In each solution, the heuristic uses the minimum number of sites in order to cover the demand points. The best solution found will be returned by the heuristic.

Algorithm IH-WNDP

Step 1: (Initialization)

Set $P := \left\{p_1, p_2, ..., p_{|P|}\right\}$.

Step 2: For $k := 1$ to $|P|$ do

2.1: Set $E_I := \emptyset$ and $E_J := \emptyset$.

2.2: If $|I \setminus E_I| > 0$ do go to Step 2.3. Otherwise go to Step 2.4.

2.3: (Find the localisation of the APs)

2.3.1: For all $j \in J \setminus E_J$ do

2.3.1.1: Find the set $\Gamma(j)$ defined as the set of demand points in $I \setminus E_I$ associated to an AP of power p_k installed at site j by using constraints (4).

2.3.2: While $E_I \neq I$ do

2.3.2.1: Let $j^* \in J \setminus E_J$ the value of j that maximize $|\Gamma(j) \setminus E_I|$. Set $E_J := E_J \cup \{j^*\}$, $E_I := E_I \cup \Gamma(j^*)$.

2.4: For each site $j \in J$ do

2.4.1: If $j \in E_J$ set $\sigma_j := \overline{p}$. Otherwise, set $\sigma_j := 0$.

2.5: Solve WNDP(σ) as described in Section 3.1.

2.6: Compute the cost of the solution found given by the objective function (18). If the cost of the current solution is less than that of the best solution obtained so far, update this best solution.

Step 3: (Termination test)

Return the best solution found and stop.

4 Numerical Results

In this section, we present the numerical results. First, in Section 4.1, we present the propagation model used for the tests, in Section 4.2, we present a lower bound and in Section 4.3, we present the numerical results and an analysis of these results.

The wireless network standards IEEE 802.11a and IEEE 802.11b are considered for the tests. Table 1 presents the principal features of these standards (for more information, see the book by Gast [8]).

4.1 Propagation Model

In the WNDP formulation, we need to evaluate the α and β parameters. These parameters can be measured in the building or evaluated using a propagation model.

Table 1: Features of the IEEE 802.11a and 802.11b standards

	IEEE 802.11a	IEEE 802.11b
Frequency band	5 GHz	2.4 GHz
Data rates	6, 9, 12, 18, 24, 36, 48, 54 Mbps	1, 2, 5.5, 11 Mbps
Number of non-overlapping channels	8	3

Several propagation models are proposed in the literature to evaluate the path loss. In this paper, we use an adaptation of the model proposed by Hata [10]. This model computes the propagation loss as a function of the distance d, the number of intermediate obstacles (e.g., walls and floors of different types) crossed by the ray (from the transmitter to the receiver) and an average loss parameter n (typically computed using measurements).

$$\overline{L}_p(d)(\text{dB}) = L_s(d_0)(\text{dB}) + 10n\log_{10}\left(\frac{d}{d_0}\right) + n_k\Delta_k(\text{dB}) \tag{19}$$

where d_0 is the reference distance, n_k, the number of obstacles of type k crossed by the ray (from the transmitter to the receiver) and Δ_k, the attenuation (in dB) for each crossing of an obstacle of type k. $L_s(d_0)(\text{dB})$ is the free space loss at distance d_0 given by the following equation.

$$\overline{L}_s(d_0)(\text{dB}) = 10\log_{10}\left(\frac{4\pi d_0}{\lambda}\right)^2 \tag{20}$$

where λ is the wavelength of the propagation signal.

Considering the 802.11a standard in an open space environment, we found that

$$\overline{L}_{802.11a}(d)(\text{dB}) = 42.68 + 36.90\log_{10}(d) + 25f \tag{21}$$

where d is the distance (in meter) and f is the number of floors crossed by the ray. For the 802.11b standard, this equation is

$$\overline{L}_{802.11b}(d)(\text{dB}) = 73.45 + 21.06\log_{10}(d) + 25f. \tag{22}$$

4.2 The Lower Bound

The results are compared to a lower bound (denoted LB-WNDP) obtained as follows. The lower bound LB-WNDP is obtained by using the CPLEX Mixed Integer Solver [12] to solve WNDP

with the constraints (4) and (8) linearized (using Proposition 3), with inequality (13), without constraints (5), (7) and (9) and without the **z** variables. As a result, the channel assignment subproblem is not included in the formulation of the lower bound. The default settings of CPLEX are used for the tests.

4.3 Numerical Results

All the algorithms were programmed in the C language and tested on a SunFire 4800 (900 MHz and 8 GB of RAM). Table 2 presents the maximum number of stations that can be associated to an AP n_{max} to respect a minimum bandwidth per station of 500 kbps, Table 3 presents the minimum signal power (in dBm) from an AP necessary for association, and Table 4 presents the minimum SNR (in dB) to reutilize a channel according to the standard (i.e., 802.11a or 802.11b) and the data rate used. These values have been found using Cisco Aironet 1200 APs and wireless adapters [6].

Table 2: Maximum number of stations n_{max} to respect t_{min}=500 kbps

IEEE 802.11a	
Data rate	Maximum number of stations
6 Mbps	10
18 Mbps	26
54 Mbps	58
IEEE 802.11b	
Data rate	Maximum number of stations
1 Mbps	2
5.5 Mbps	7
11 Mbps	10

The power levels used for the tests are 5, 10, 20 and 40 mW for 802.11a and 1, 5, 20, 30, 50 and 100 mW for 802.11b. These values are those available for Cisco Aironet 1200 APs [6].

The MaxIter parameter of TS-WNDP is set to 100, the interval $[L, U]$ to $[5, 10]$ and the penalty factor to 100, because the best solutions was found within 100 iterations and with this interval.

For the tests, we consider a 10-floors building, each floor having an area of 5 000 square meters. Moreover, 400 potential sites are considered in the building to install the APs (i.e., $|J| = 400$). Each

Table 3: Minimum signal power p_{min} (in dBm) from an AP necessary for association

IEEE 802.11a	
Data rate	Minimum signal power
6 Mbps	-85 dBm
18 Mbps	-80 dBm
54 Mbps	-68 dBm
IEEE 802.11b	
Data rate	Minimum signal power
1 Mbps	-94 dBm
5.5 Mbps	-89 dBm
11 Mbps	-85 dBm

Table 4: Minimum SNR d_{min} (in dB) to reutilize a channel

IEEE 802.11a	
Data rate	Minimum SNR
6 Mbps	13 dB
18 Mbps	21 dB
54 Mbps	30 dB
IEEE 802.11b	
Data rate	Minimum SNR
1 Mbps	10 dB
5.5 Mbps	17 dB
11 Mbps	22 dB

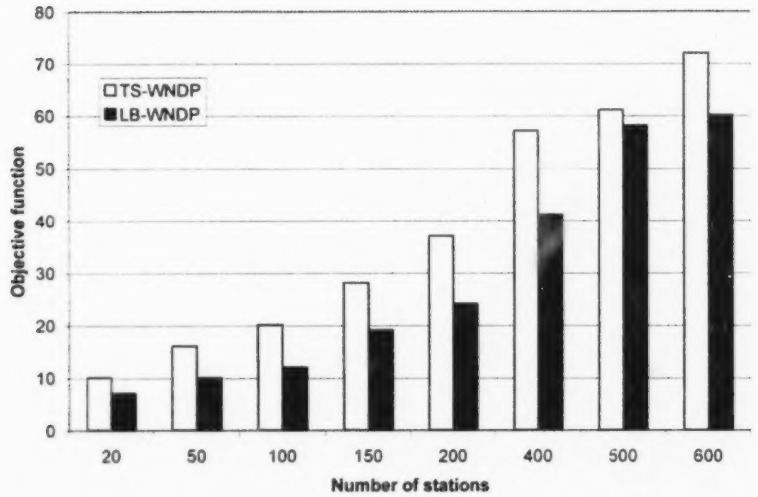

Figure 2: Computational results for TS-WNDP and LB-WNDP for 802.11a (6 Mbps)

test problem is generated as follows. $|I|$ points corresponding to station' locations (i.e., one station per demand point) were located in the building following a uniform distribution.

Figures 2 and 3 present the computational results for 802.11a with the data rate fixed respectively to 6 Mbps and 18 Mbps. From these figures, it can be seen that the algorithm TS-WNDP gives solutions relatively far from the lower bound, especially when the number of stations is large. This can be explained by the fact that the channel assignment variables and constraints are not considered to find the lower bound. As a result, solutions far from feasibility are found. We have tried to improve the value of the lower bound by considering these constraints and variables but we did not succeed to solve it using CPLEX.

Figure 4 presents the computational results for 802.11a with the data rate fixed to 6 Mbps and 18 Mbps and the computational results for 802.11b with the data rate fixed to 11 Mbps. From this figure, it can be seen that our algorithm for 802.11b is not able to find a feasible solution for the tests problems with 400, 500 and 600 stations. This is due to the small number of non-overlapping channels available in the 802.11b standard. For those test problems, the 802.11a standard should be used. Moreover, when the number of stations is small (i.e., for the test problems with 20, 50 and 100

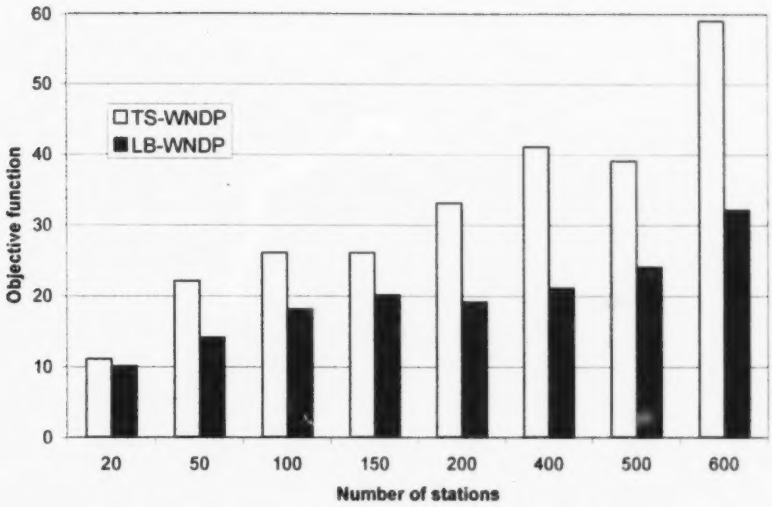

Figure 3: Computational results for TS-WNDP and LB-WNDP for 802.11a (18 Mbps)

stations) better solutions are obtained when the data rate is set to 6 Mbps rather than to 18 Mbps. This is because, for a given standard, the maximal range of an AP is larger when the data rate fixed is lower. Indeed, for 802.11a standard, the maximal range is 52 meters for 6 Mbps and 40 meters for 18 Mbps. As a result, when the density of the stations is small, the data rate should be set carefully.

Figure 5 presents the CPU times for the algorithms TS-WNDP and LB-WNDP for 802.11a with the data rate fixed to 18 Mbps. This figure shows that the CPU time is only 2000 seconds for the largest test problem with 600 stations. However, the CPU time of LB-WNDP increase rapidly according to the number of stations.

Figure 6 presents the computational results for 802.11a with the data rate fixed to 18 Mbps for the minimum bandwidth per station t_{min} equals to 250 kbps, 500 kbps and 1 Mbps. This figure shows that when the number of stations is small, the values of the solutions are equal. However, for large-size test problems, more APs are necessary with an increasing of the value of the minimum bandwidth per station.

Finally, the study of the influence of the architecture on the results is illustrated in Figure 7. The values of the solutions for a 10-floors building (e.g., an office tower) and for a one-floor building (e.g.,

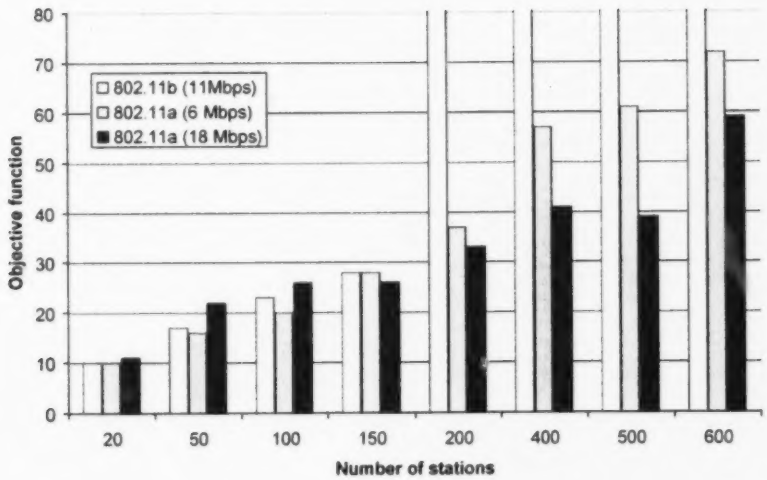

Figure 4: Computational results for TS-WNDP and LB-WNDP for 802.11a and 802.11b

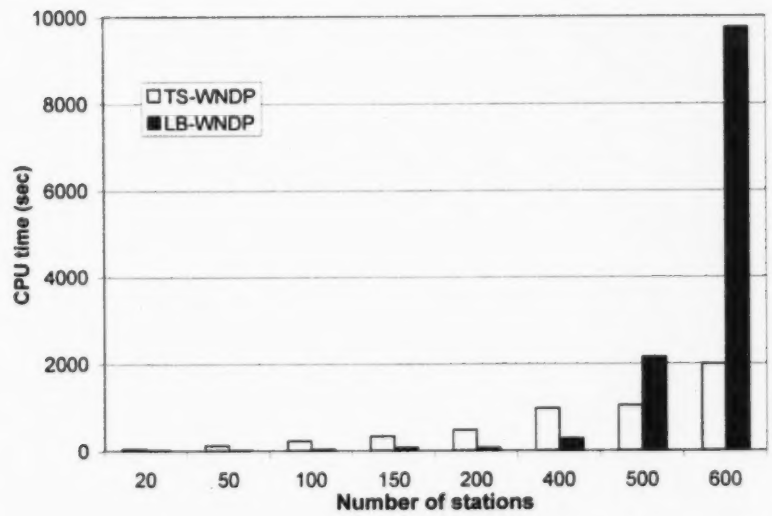

Figure 5: CPU times for TS-WNDP and LB-WNDP for 802.11a (18 Mbps)

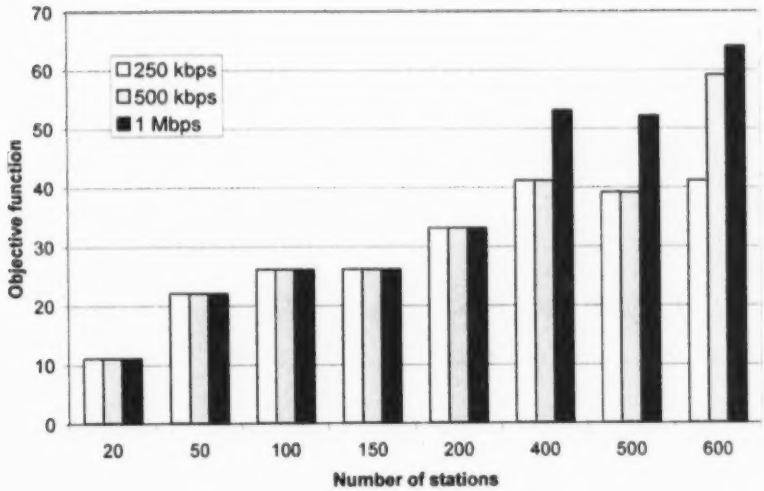

Figure 6: Computational results for TS-WNDP for 802.11a (18 Mbps) for t_{min}=250 kbps, 500 kbps and 1 Mbps

an airport) are compared when using the 802.11a standard with the data rate fixed to 18 Mbps. The figure shows that, except for the test problems having 20 and 150 stations, the values of the solutions are better with the one-floor building. This is simply due to the fact that the propagation of the signals is better in a one-floor building rather than in a 10-floors building.

5 Conclusions

In this paper, we have studied the problem of designing WLAN and proposed an optimization model for selecting the location of the APs and selecting power and the channel of each APs. After making some realistic assumptions about their organization, we have presented a mathematical formulation of this design problem. A heuristic for generating initial solutions and a tabu search algorithm for improving this initial solution have been proposed.

The results were compared to a proposed lower bound obtained by relaxing a subset of the original constraints in the model. These results have shown that the tabu-based heuristic produces relatively good solutions rapidly. However, it would be interesting to improve the lower bound formulation in order to evaluate effectively the proposed heuristic. Another research direction is to explore exact

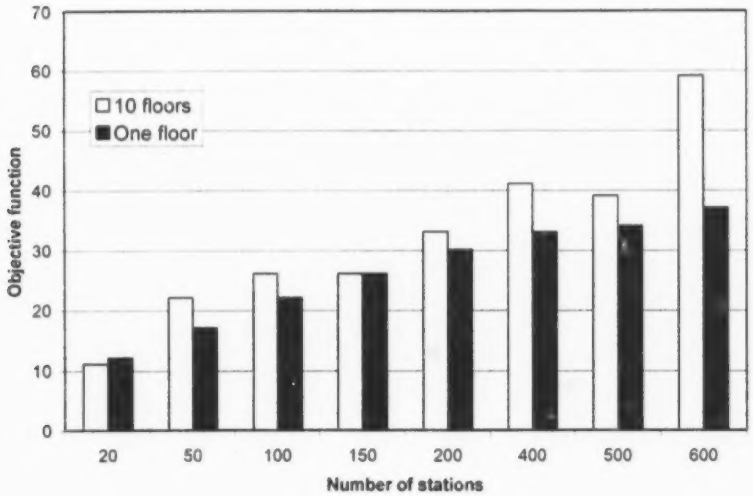

Figure 7: Computational results for TS-WNDP for 802.11a (18 Mbps) for two types of building having the same surface

algorithms to solve small-size instances of the problem.

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